

EFFECTS OF SULPHUR DIOXIDE AND HEAVY METALS ON VEGETATION IN THE WAWA AREA (1973)

May, 1974

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Ontario

Ministry
of the
Environment

The Honourable
William G. Newman,
Minister

Everett Biggs,
Deputy Minister

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Effects of Sulphur Dioxide and Heavy Metals
on Vegetation in the Wawa Area (1973)

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Ontario Ministry of the Environment
Sudbury, Ontario
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I. Sulphur Dioxide Levels in the Wawa Area During the 1973 Season:

(a) Introduction:

The program which was set up in 1961 to monitor the ground level concentrations of sulphur dioxide emitted from the Algoma Ore Division and the Algoma Steel Corporation Sinter Plant at Wawa was continued during the 1973 season (May to October). Two continuous SO₂ monitors and a network of eight sulphation candles were used to record the sulphur dioxide levels in the area.

One continuous sulphur dioxide monitor was operated at Goudreau, 22 miles northeast of Wawa during the season. Ground level concentrations of SO₂ have been recorded at this station for the past 13 seasons. The other continuous sulphur dioxide monitor was operated at 29 Hillcrest Avenue, Wawa, and SO₂ data has been recorded at this station for the past 5 seasons. The sulphation candles were exposed adjacent to eight vegetation study plots established by the Phytotoxicology Section in the Wawa area. (See map appended).

(b) Sulphur Dioxide Levels Recorded in the Town of Wawa During the 1973 Season:

The Air Quality and Meteorology Section of the Ontario Ministry of the Environment operated a continuous Davis SO₂ analyser in the town of Wawa from May 17th to October 17th, 1973. During this period of operation, valid SO₂ data was collected about 95% of the total time. A summary of the SO₂ levels recorded at this station over the past 5 years is shown in Table 1 of this report.

During June, 1973, some level of sulphur dioxide was recorded for 60.2% of the operative period. This is considerably higher than in the same month during the 4 previous seasons. This is partly due to the fact that a different instrument was used in Wawa during the 1973 season than the previous four seasons. The Davis analyser is an extremely sensitive, low range instrument which records low level concentrations of sulphur dioxide which the Thomas autometer, the instrument used during 1969-1972, would not record. In June, 94% of the SO₂ readings were below 0.04 ppm. Sulphur dioxide was recorded 23.3% of the time in July, 7.5% of the time in August, 18.7% in September and 29.7% in October. Some level of SO₂ was recorded 31.5% of the total operative period.

Half-hour concentrations of SO₂ in excess of 0.25 ppm were recorded in the town of Wawa each month of 1973 except June. In July, August, September and October, the 0.50 ppm level was exceeded and during the months of September and October the 1.50 ppm level was exceeded. There was no record high half-hour concentration established for any month during the season of 1973 compared to previous years.

The average monthly concentration for SO₂ periods only and total period for the 1973 season were in general lower than those for the corresponding months of previous seasons. The seasonal average for SO₂ periods only was 0.05 ppm which is considerably lower than the average for previous seasons. The average SO₂ concentration for the 1973 total period was 0.01 ppm the same as for the 4 previous seasons.

Field observations made in the Sudbury and Wawa areas over the past several years indicate that acute sulphur dioxide injury can result on vegetation when the following daytime concentrations of sulphur dioxide are reached or exceeded for the following time periods:

0.95 ppm for 1 hour
or 0.55 ppm for 2 hours
or 0.35 ppm for 4 hours
or 0.25 ppm for 8 hours

An intensity factor of 100 has been assigned to any one of the above combinations.

During the 1973 season four potentially injurious fumigations were recorded in the town of Wawa. Three occurred in September and one in October. On September 11th, 1973, a fumigation with an intensity of 266 was recorded. This is the highest intensity ever recorded at Wawa. If these four potentially injurious fumigations had occurred in June, July or August severe acute vegetation injury probably would have occurred.

(c) Sulphur Dioxide Levels Recorded at Goudreau During the 1973 Season:

During 1973, a continuous sulphur dioxide analyser was operated at Goudreau (21.6 miles northeast of Wawa) from May 19th to October 15th. Valid sulphur dioxide data was collected for approximately 95% of this period.

In tables 2 and 3 of this report the data collected at Goudreau during 1973 are summarized.

During the 1973 season SO₂ was recorded 17.7% of the time. Six percent of the SO₂ readings were above 0.25 ppm, 1.8% above 0.50 ppm and only 0.2% above 1.00 ppm. Most of the SO₂ readings above 0.25 ppm and 0.50 ppm occurred during May, September and October.

The maximum $\frac{1}{2}$ -hour concentration was 1.38 ppm and this occurred on October 3rd. Half-hour concentrations in excess of 0.50 ppm were recorded every month except June.

In table 3 of this report the monthly and seasonal average concentrations of sulphur dioxide for sulphur dioxide periods only and total period are compared to the ten year mean for each month.

The seasonal average for the total period was 0.014 ppm (10 year mean is 0.012 ppm) and for SO₂ periods only the average is 0.082 ppm (10 year mean is 0.069 ppm). The average concentrations for SO₂ periods only and total period was higher than the 10 year mean in May, August, September and October.

Potentially injurious fumigations were recorded at Goudreau on three occasions during 1973. One occurred on May 30th with an intensity of 106, one on July 29th with an intensity of 118 and one on October 7th with an intensity of 221. The fumigation of July 29th caused acute injury on the indigenous vegetation in the Goudreau area, reaching to a distance of about 25 miles northeast of the sinter plant. There had only been one potentially damaging fumigation recorded at Goudreau in the previous 13 seasons.

(d) Use of Low Sulphur Content Ore During the Growing Season:

The Algoma Ore Division initiated a program in 1961 whereby selected low-sulphur content ore was processed during the growing season (mid May to mid September) and the higher sulphur content ore processed during the non-growing season. It is difficult to evaluate the success of this program as there is no way of assessing what the extent of vegetation injury by sulphur dioxide would have been had the program not been in effect. In table 4 of this report the summary of the program for the 1973 season is shown (data furnished by the Algoma Ore Division). A total of 32,557 gross tons of sulphur was emitted to the atmosphere during the 1973 growing season. In table 5 of this report the production data for the 1973 season is compared to that for the previous seasons. While the amount of SO₂ emitted into the atmosphere during 1973 was not a record high, it was considerably higher than the amount emitted in 1972.

This program, over the past 13 years, has had a measure of success in limiting the extent and incidence of vegetation injury in the Wawa area, however, severe acute sulphur dioxide injury has occurred in the Wawa area in spite of the program.

II. Vegetation Injury by Sulphur Dioxide in the Wawa Area During 1973:

During the 1973 growing season (mid May to mid September), more sulphur dioxide was emitted to the atmosphere from the Algoma Ore Division sinter plant at Wawa, than in many of the previous seasons since the use of low sulphur content ore began in 1961. As would be expected, this resulted in vegetation being injured more frequently and over a larger area than in previous seasons. Some degree of acute sulphur dioxide injury (visible injury, caused by short-term high concentration fumigations) occurred on indigenous species of vegetation over approximately a 125 square mile area northeast of the sinter plant in 1973. Some injury occurred to the southwest of the plant also but this was confined to a two or three square mile area.

No acute sulphur dioxide injury occurred on trees, vegetables or ornamentals in the town of Wawa during 1973. The four potentially injurious fumigations which were recorded in the town occurred late in the season when vegetation was relatively resistant to sulphur dioxide.

By the third week in June, trace (0-5% of leaf area affected) to light injury (6-15% of the leaf area affected) was evident on vegetation over about an eighty square mile area northeast of the sinter plant. Trembling aspen, white birch, mountain ash, mountain maple and red raspberry were the plant species most commonly affected.

By mid July the area over which vegetation injury had occurred had increased from approximately 80 square miles to approximately 125 square miles and for the first time during the season moderate injury (16-35% of leaf area affected) and severe injury (over 35% of leaf area affected) were noted. Severe injury occurred on such trees as white birch, trembling aspen, showy mountain ash and pin cherry at distances up to about 15 miles northeast of the sinter plant. Trace to moderate injury was noted on these four tree species up to a distance of about 25 miles northeast of the sinter plant. Acute SO₂ injury occurred on shrubs such as honeysuckle, speckled alder and several species of ground cover vegetation over about a 125 square mile area northeast of Wawa in July. The most severe injury on these plant species occurred within about 15 miles of the plant.

In August trace to severe SO₂ injury occurred over about the same area as in July but affected more plant species. Light to moderate injury occurred on larch and jack pine as far out from the plant as 15 miles to the northeast.

No new SO₂ injury was noted in the Wawa area in September, however, the injury which occurred during June, July and August was still visible. Many of the severely damaged leaves were shed prematurely on affected trees early in September. This was particularly evident on white birch trees within a distance of 15 miles to the northeast of the plant.

III. Wawa Area Vegetation Study Plots - Program Outline:

In 1969, the Phytotoxicology Section of the Air Management Branch in co-operation with the White River District of the Ministry of Natural Resources established six surveillance plots in a transect line northeast of the sinter plant and two control plots located outside the Fume Damage Area (35 miles from the sinter plant) as follows:

<u>Plot No.</u>	<u>Distance and Direction from the Sinter Plant</u>
1	10 miles northeast
2	12 miles northeast
3	16 miles northeast
4	19 miles northeast
5	22 miles northeast
6	24 miles northeast
7	38 miles northeast
8	35 miles northwest

When the surveillance plots were established in 1969, 10 trees (trembling aspen and/or white birch) and 10 shrubs (showy mountain ash, mountain maple, prairie willow, red osier dogwood, elderberry, pin cherry, speckled alder, beaked hazel, or serviceberry) were tagged in a 66 ft. x 66 ft. area at each plot. The "crown condition" of the trees was recorded along with insect, disease, or sulphur dioxide injury in order to establish a history of the vegetation on the plots. These conditions were again observed in June, July, and August from 1970 to 1973. As well, in September of each year the heights and diameters of the tagged trees were recorded for use in growth studies.

At each plot, two 3.3 ft. x 3.3 ft. ground cover vegetation grids were established and the number and species of each type of plant found on these grids were recorded to determine any differences in populations with distance from the sinter plant and any future fluctuations in plant populations. These grids were re-examined in August from 1970 to 1973.

A program of sampling the vegetation and soil for chemical analysis was also initiated in 1970. Leaf samples from trembling aspen, white birch, mountain maple (or substitute); forage and soil were collected from each of the plots in June, July, August, and September and analysed for fluoride, total sulphur, arsenic, iron, and zinc. This sampling was continued in June, July, and August from 1971 to 1973.

Analysis of fluoride was not continued when the 1970 analysis showed that this element was not found to be a problem in the Wawa area.

In 1970, a lead peroxide candle, to measure ambient levels of sulphur dioxide, was set out at each of the vegetation plots and these candles were exchanged at monthly intervals throughout the 1970, 1971, 1972 and 1973 growing seasons.

Observations:

(a) Tree Crown Conditions:

The "crown condition" classification system employed was one developed by the Canadian Forestry Service for hardwood species in Ontario. A classification gradation from 1A (healthy) to 6B (dead), with several intermediate conditions, allows for an informative description of the crown condition at the time of surveillance.

Table 6 shows the changes in crown conditions of the trees and shrubs on the vegetation study plots from 1969 to 1973. Table 7 shows the distribution of the trees and shrubs on the study plots with regard to their crown condition in August, 1973. These charts indicate that deterioration is occurring at plots 1 and 2. These two plots show the greatest number of trees which are declining and together with plot 3 show the largest number of trees with conditions lower than 3A. A condition lower than 5A indicates that the tree is dying-back severely in the crown and down the trunk. At plot #6, interference by human activity has caused deterioration and death of a number of specimens. At plot #7, extensive injury has been caused by wind uprooting large trees on and around the plot. Also at this location, moose browsing has reduced the crowns on many of the shrubby species. As has been pointed out in previous reports, continued heavy emissions from the sinter plant will induce further declines in the crown conditions of the trees and shrubs on the plots in the fume damage zone, especially at plots 1 and 2.

(b) Plant Population Studies:

The recording of the plant populations in the two grids established adjacent to each of the eight Wawa vegetation plots has been in progress for five growing seasons. Various applications of statistical analysis are presently being considered for these data, in order to obtain a better understanding of the implications of the fluctuations in plant populations over the past five years. Table 8 shows the number of species of trees, shrubs and herbaceous plants present in the grids from 1969 to 1973. It also shows the number of individuals for these plant types. Some plants are more easily tallied as clumps or patches (taking area covered into consideration)

and these have also been listed in addition to the number of individuals. Mosses, grasses, and sedges, etc. have not always been species-identified, therefore, only the number of clumps or patches of this group has been listed for each year. From this table it can be seen that although the number of species of trees, shrubs and herbs does not fluctuate to any degree from year to year, there have been quite wide variations, on occasion, in the numbers of individuals or clumps. Such variations are also apparent in the grids located at the control plots.

There is some doubt therefore as to whether or not these variations are the result mainly of fluctuations in the ambient SO₂ levels, or whether local conditions and micro-habitat are the dominating factors. The statistical analysis of the data will seek correlations between some of these features and the variations in plant populations over the study period. There is no question that in the area of severe damage in the centre of the valley running northeast of the sinter plant, the number of species and individuals is severely restricted. However after examining the present data, this same restriction is not being carried over to the sides of the valley where the plots are located. This portion of the study is now under review and may be altered to provide a better picture of the situation as it exists in the Wawa fume damage area.

(c) Chemical Analysis of Vegetation and Soil Samples (1970-1973):

The chemical analysis of the samples collected in 1973 is still in progress at the time of writing this report. The 1970 to 1972 data have been compiled and subjected to statistical analysis. Table 9 shows the results of the chemical analyses for vegetation and soil samples at the eight study plots. The table of analysis of variance (Table 10, F - Values) shows that for sulphur, arsenic, iron and zinc the differences between the species were significant at the 1% level for both the 1970 and 1971 collections. In 1972, the iron levels were significantly different at the 5% level, while the arsenic levels were similar statistically from one species to another. The sulphur and zinc levels remained significantly different at the 1% level. These results indicate that the level of a given element in a single species is not necessarily comparable to the level of that element in another species.

The table of analysis of variance also shows that for sulphur, arsenic, iron and zinc, their concentrations in the vegetation are significantly different at the 1% level from station to station from 1970 to 1972. For this three year time period, the levels recorded at plots 1 to 3 are significantly higher than the remainder of the plots.

From table 9 it can be seen that the sulphur levels in trembling aspen, white birch, mountain maple and showy mountain ash

were generally at their highest level in 1972 for the three years at plots 1 to 4. This corroborates the earlier observation that the output by the sinter plant was over 30,000 gross tons of sulphur as SO_2 during the growing season; that the sulphation rates continued to be above the criterion of $0.4 \text{ mgm SO}_3/100 \text{ cm}^2/\text{day}$ (especially at plots 1 and 2); and that acute SO_2 vegetation injury was high in this area during 1972. The levels of arsenic, iron and zinc were elevated mainly at plots 1 and 2.

In the soil, arsenic and iron were elevated at plots 1 and 2. These levels however should not affect the growth of vegetation on or around these two plots. Higher levels of these two elements have been found in the soil in the more severely damaged areas.

(d) Lead Peroxide Candle Survey:

The values of sulphur recorded on the lead peroxide candles set out at each of the plots, expressed as $\text{mgm SO}_3/100 \text{ cm}^2/\text{day}$, are shown in table 11. The Ontario sulphation criterion for desirable ambient air quality is $0.4 \text{ mgm SO}_3/100 \text{ cm}^2/\text{day}$. The values registered at plots 1 to 4 were higher than this criterion on many occasions. This is also the region where the most extensive SO_2 injury to vegetation had occurred. The values registered at plots 5 and 6 were usually within the criterion, but still higher than the background levels recorded at the control plots 7 and 8.

It has been found over the period from 1970 to 1972 that the levels of sulphur found in the vegetation were closely correlated to the sulphation rates as recorded on the lead peroxide candles. Table 12 shows the average sulphation rates for June, July, and August for 1970 to 1972 and the average concentration of sulphur in the vegetation for the same periods. Also shown in table 12 are the regression equations and correlation coefficients for these years.

It can be seen from this table that the correlation between these two factors was significant at the 5% level ($r = 0.84$) in 1970 and the 1% level ($r = 0.96$ and $r = 0.95$) in 1971 and 1972, where r is the correlation coefficient.

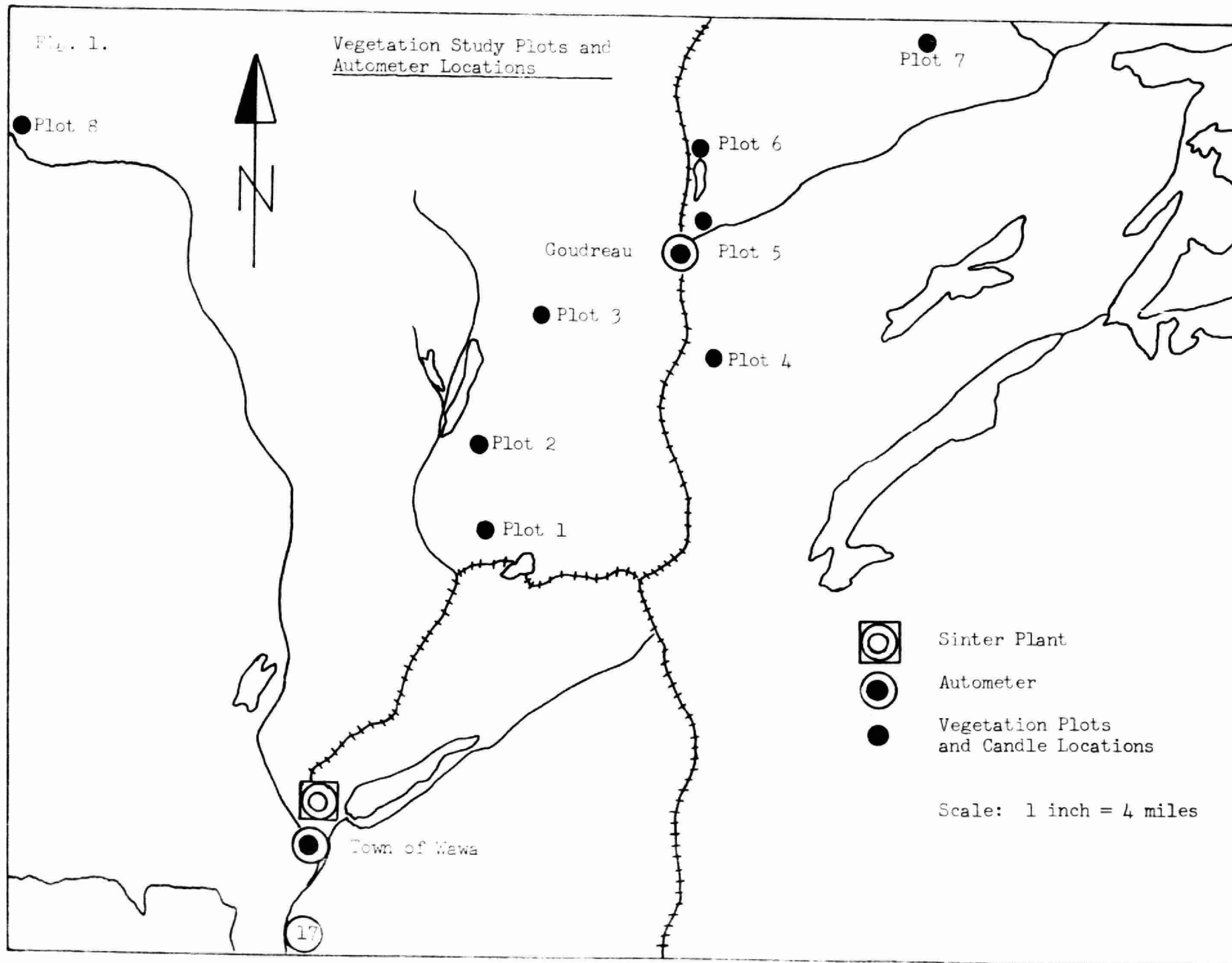
IV. Conclusion:

For three years in succession, phytotoxicology studies have indicated that deterioration of vegetation is occurring in the fume damage region, mainly in the area of plots 1 and 2 (up to 12 miles to the northeast of the sinter plant). Ground level concentrations of SO₂ continued to be high and such levels have been correlated to environmental contamination and injury to vegetation during this period. In 1961, the sinter plant commenced the utilization of low-sulphur content ore. The amending abatement control order issued in December, 1973, requires the construction of a tall stack by the 1978 growing season. Until that time, it can be expected that injury to vegetation will continue in the Wawa fume damage area. The data gathered to date and in the coming seasons will serve as baseline information to evaluate the performance of the taller stack in reducing ground level SO₂ concentrations and related vegetation injury. During 1974, the Ministry of the Environment will continue to monitor ambient SO₂ levels, sample vegetation and soil, and describe vegetation growth and plant injury in the Wawa area.

V. Acknowledgments:

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APPENDIX



Plot Locations and Site Descriptions

Plot #1 Location:

Parks Lake located in the "Total Kill" section of the Fume Damage area 10 miles northeast of the sinter plant.

Site Description:

Open, low shrubby area, few (20') trees; rocky outcrops, soil thin, vegetation sparse in exposed sites, dense in protected, damp sites; many grassy or "weedy" glades.

Plot #2 Location:

Finger Lake located in the "Total Kill" section of the Fume Damage area, 12 miles northeast of the sinter plant.

Site Description:

Low trees and shrubs canopy; shrubs dense; rocky outcrops, soil thin, little humus; similar to Plot #1.

Plot #3 Location:

Perry Lake located in the "Heavy Kill" section of the Fume Damage area, 16 miles northeast of the sinter plant.

Site Description:

Dense spruce-fir canopy, trees 30' tall, thick humus layer, few rock outcrops, many seedlings.

Plot #4 Location:

Garbe Lake located in the "Heavy Kill" section of the Fume Damage area, 19 miles northeast of the sinter plant.

Site Description:

Open spruce-birch canopy; thin humus, medium to dry soil, many rocky outcrops.

Plot #5 Location:

Goudreau townsite located in the "Light Damage" section of the Fume Damage area, 22 miles northeast of the sinter plant.

Site Description:

Dry open woods with aspen predominating on a south slope, disturbed site, many "weedy" species.

Plot #6 Location:

Herman Lake located in the "Light Damage" section of the Fume Damage area, 24 miles northeast of the sinter plant.

Site Description:

Small island, disturbed by habitation; white birch dominating, open, low shrub cover; many "weedy" species, gravelly lake shore.

Plot #7 Location:

Control plot located outside the Fume Damage area near Crouche Lake, 38 miles northeast of the sinter plant.

Site Description:

20° slope with a southern exposure; soil thin, dry; abundant litter; canopy open; trembling aspen and maple dominant.

Plot #8 Location:

Control plot located outside the Fume Damage area in Obatanga Provincial Park, 35 miles northwest of the sinter plant.

Site Description:

Mixed habitat; spruce and fir canopy, boggy area, lake edge; abundant soil moisture, rich humus layer; canopy recently opened by wind throw.

(see Fig. 1 for plot locations)

Note: The terms, Fume Damage Area; Total Kill; Heavy Kill; and Light Damage, refer to the designations assigned to the various areas by the Ministry of Natural Resources during their aerial surveys of the region to assess the impact of the sinter plant fumes on white birch in the area.

Table 1 :

Summary of the Sulphur Dioxide Data Recorded
in the Town of Wawa During 1969, 1970, 1971, 1972 and 1973

Year	Total Sampling Time (hrs.)	Zero Readings		Readings		Maximum ½ hour Concentration (ppm)	Average ppm for	
		hrs.	%	hrs.	%		SO ₂ Periods Only	Total Period
-----June-----								
1969	152.0	150.0	98.7	2.0	1.3	0.35	.17	.01
1970	651.0	634.5	97.4	16.5	2.5	0.48	.09	.01
1971	537.0	524.0	97.5	13.0	2.4	1.73	.26	.01
1972	535.5	526.5	98.3	9.0	1.7	0.40	.05	.01
1973	704.0	280.5	39.8	423.5	60.2	0.17	.01	.01
-----July-----								
1969	744.0	726.0	97.6	18.0	2.4	0.14	.05	.01
1970	744.0	740.5	99.6	3.5	0.4	0.10	.06	.01
1971	743.0	727.0	97.8	16.0	2.1	0.72	.10	.01
1972	738.0	724.5	98.2	13.5	1.8	0.26	.05	.01
1973	744.0	571.0	76.7	173.0	23.3	0.65	.02	<.01
-----August-----								
1969	744.0	744.0	100.0	0.0	0.0	0.00	.00	.00
1970	744.0	728.0	97.8	16.0	2.2	1.22	.25	.01
1971	725.0	712.5	98.2	12.5	1.7	0.63	.20	.01
1972	739.0	706.5	95.6	32.5	4.4	1.22	.09	.01
1973	731.0	676.0	92.5	55.0	7.5	0.63	.03	<.01

Table 1 (cont'd):

Summary of the Sulphur Dioxide Data Recorded
in the Town of Wawa During 1969, 1970, 1971, 1972 and 1973

<u>Year</u>	<u>Total Sampling Time (hrs.)</u>	<u>Zero Readings</u> <u>hrs.</u> <u>%</u>	<u>Readings</u> <u>hrs.</u> <u>%</u>	<u>Maximum</u> <u>½ hour</u> <u>Concentration</u> <u>(ppm)</u>	<u>Average ppm for</u> <u>SO₂ Periods</u> <u>Total</u> <u>Only</u> <u>Period</u>
-----September-----					
1969	744.0	744.0 100.0	0.0 0.0	0.00	.00 .00
1970	720.0	702.5 97.6	17.5 2.4	0.38	.12 .01
1971	183.0	175.5 95.9	7.5 4.0	1.84	.51 .02
1972	418.5	403.0 96.3	15.5 3.7	0.39	.11 .01
1973	717.0	583.0 81.3	134.0 18.7	1.79	.13 .02
-----October-----					
1969	512.5	512.5 100.0	0.0 0.0	0.00	.00 .00
1970	488.0	462.0 94.7	26.0 5.3	0.78	.15 .01
1971	471.5	461.5 97.8	10.0 2.0	1.06	.22 .01
1972	611.5	558.0 91.3	53.5 8.7	2.03	.39 .04
1973	372.0	261.5 70.3	110.5 29.7	1.78	.19 .05
-----Season-----					
1969	2872.5	2852.5 99.3	20.0 0.7	0.35	.06 .01
1970	3618.5	3531.0 97.6	87.5 2.4	1.22	.16 .01
1971	2658.5	2600.5 97.8	59.0 0.2	1.84	.23 .01
1972	3214.0	3085.0 96.0	129.0 4.0	2.03	.21 .01
1973	3540.5	2427.0 68.5	1113.5 31.5	1.79	.05 .01

Table 2:

Summary of the Sulphur Dioxide Data Recorded
at Goudreau During the 1973 Season.

Total Sampling Time (hr.)	Total Hours of		Hours Above						Maximum $\frac{1}{2}$ -hr. Concentration
	<u>SO₂</u>	<u>%</u>	0.25 ppm	%	0.50 ppm	%	1.00 ppm	%	
			-May-						
322.5	53.5	16.6	7.5	14.0	1.5	2.8	0.0	0.0	0.61
			-June-						
678.0	185.0	27.3	2.5	1.3	0.0	0.0	0.0	0.0	0.46
			-July-						
592.0	98.0	16.5	3.0	3.1	1.0	1.0	0.0	0.0	0.97
			-August-						
702.0	135.0	19.2	4.5	3.3	1.0	1.0	0.0	0.0	0.53
			-September-						
714.5	75.5	10.6	8.0	10.6	2.5	3.3	0.0	0.0	0.97
			-October-						
195.0	47.5	24.4	10.0	21.1	4.5	9.5	1.0	2.1	1.38
			-Season-						
3353.5	594.5	17.7	35.5	6.0	10.5	1.8	1.0	0.2	1.38

Table 3: Average Monthly SO₂ Concentrations at
Goudreau During 1973 Compared to the 10 Year Mean.

<u>Month</u>	<u>Average ppm for SO₂ Periods Only</u>		<u>Average ppm for Total Period</u>	
	<u>Mean</u>	<u>1973</u>	<u>Mean</u>	<u>1973</u>
May	0.070	0.116	0.008	0.019
June	0.067	0.057	0.017	0.015
July	0.075	0.075	0.018	0.012
August	0.062	0.071	0.011	0.013
September	0.064	0.091	0.007	0.009
October	0.082	0.168	0.008	0.023
Season	0.069	0.082	0.012	0.014

Table 4:

Algoma Ore Division
The Algoma Steel Corporation, Limited

Sulphur in Sinter Plant Raw Ore Feed and Sinter Produced

Dried Weights and Assays

<u>Date</u> <u>1973</u>	<u>Raw</u> <u>Ore Feed</u> <u>Gross Tons</u>	<u>Sulphur in Feed</u> <u>%</u>	<u>Gross Tons</u>	<u>Sinter</u> <u>Produced From</u> <u>Ore G.T.</u>	<u>%</u>	<u>Sulphur</u> <u>in Sinter</u> <u>Gross Tons</u>	<u>G.T. of</u> <u>Sulphur</u> <u>Lost as SO₂</u>
May	270,509	3.13	8,466	184,354	.075	138	8,328
June	267,245	3.13	8,365	175,663	.070	123	8,242
July	246,173	3.19	7,853	163,878	.080	131	7,722
August	261,275	3.04	7,943	173,395	.099	172	7,771
September	256,715	3.71	9,524	164,766	.126	208	9,316
October	272,879	5.27	14,381	177,908	.126	224	14,157
Average 6 Month Period	1,574,796	3.57	56,220	1,039,964	.102	1,061	55,159

Table 5: Production and Emissions at Wawa During 1961-1973 Growing Seasons*

Year	Ore Feed (G.T.)	% Sulphur In Ore	Sinter Produced From Ore (G.T.)	Sulphur Lost As SO ₂ (G.T.)
1961	816,311	4.55	575,825	36,479
1962	800,697	3.66	540,700	28,657
1963	832,069	3.53	545,445	28,837
1964	893,990	3.00	562,637	26,087
1965	891,818	3.70	620,249	32,194
1966	923,785	3.19	628,930	28,790
1967	794,128	3.24	543,377	25,223
1968	926,734	3.38	609,406	30,822
1969	554,339	3.39	364,554	18,479
1970	733,630	3.00	434,726	18,069
1971	1,002,012	3.35	654,892	32,723
1972	926,164	3.33	622,332	30,342
1973	1,038,304	3.24	687,496	32,557

* Production Data supplied by the Algoma Steel Corporation Limited

Table 6 : Summary of the Changes in "Crown Condition" of the Trees
and Shrubs on the Wawa Vegetation Plots from 1969 to 1973.

<u>Plot No.</u>	<u>Distance and Direction from Sinter Plant</u>	Number of Trees or Shrubs where the Crown Condition has		
		<u>Remained Unchanged</u>	<u>Improved</u>	<u>Declined</u>
1	10 mi. NE	8	3	7 (+ 2 dead)
2	12 mi. NE	14	0	5 (+ 1 dead)
3	16 mi. NE	14	2	4 -
4	19 mi. NE	14	5	1 -
5	22 mi. NE	6	9	2 (+ 3 dead)
6	24 mi. NE	11	4	4 (+ 1 dead)
7 (Control)	38 mi. NE	11	1	7 (+ 1 dead)
8 (Control)	35 mi. NW	13	4	2 (+ 1 dead)

Table 7 :

Distribution of the Crown Conditions of the Trees
and Shrubs on the Wawa Vegetation Plots in August, 1973.

Plot No.	Distance and Direction from Sinter Plant	Crown Condition											
		1A Healthy	1B	2A	2B	3A	3B	4A	4B	5A Severe Decline	5B	6A	6B Dead
1	10 mi. NE	8	-	-	-	1	3	2	4	-	1	1	-
2	12 mi. NE	12	-	-	-	3	1	1	2	-	-	1	-
3	16 mi. NE	7	1	-	-	7	1	4	-	-	-	-	-
4	19 mi. NE	16	1	-	-	3	-	-	-	-	-	-	-
5	22 mi. NE	12	2	-	-	2	-	1	-	1	1	1	-
6	24 mi. NE	9	2	-	-	6	2	-	-	-	-	1	-
7 (Control)	38 mi. NE	9	2	-	-	4	1	2	-	-	1	-	-
8 (Control)	35 mi. NW	12	2	-	-	3	2	-	-	-	1	-	-

Table 8 :

Summary of the Ground Flora Populations in the Grids
Adjacent to the Wawa Vegetation Plots from 1969 to 1973

Plot No.	Location	Grid No.	Year	Trees					Shrubs					Herbaceous Plants					Grasses, Sedges, Mosses, Lichens				
				'69	'70	'71	'72	'73	'69	'70	'71	'72	'73	'69	'70	'71	'72	'73	'69	'70	'71	'72	'73
1	10 mi. NE	1	No. of Species	1	1	1	1	1	4	4	4	5	5	6	8	9	7	8	-	-	-	-	-
			No. of Individ.	12	8	5	7	6	7	9	6	8	9	287	338	407	418	400*	-	-	-	-	3
			No. of Clumps	-	-	-	-	-	19	27	22	18	10	1	5	4	-	1	-	33	29	38	33
		2	No. of Species	2	2	2	2	2	6	6	6	4	4	7	9	9	8	8	-	-	-	-	-
			No. of Individ.	2	2	2	2	2	7	7	11	8	8	166	264	265	208	153	3	2	2	1	2
			No. of Clumps	-	-	-	-	-	-	-	-	-	-	2	4	2	-	3	8	12	20	23	21
2	12 mi. NE	1	No. of Species	1	1	1	1	1	2	2	2	2	2	5	5	5	5	5	-	-	-	-	-
			No. of Individ.	11	8	4	4	4	2	2	-	1	1	221	371	333	421	223	-	-	-	-	-
			No. of Clumps	-	-	-	-	-	24	42	28	18	Vac G	7	40	44	26	38	4	10	9	13	20
		2	No. of Species	1	1	1	-	-	4	4	4	4	3	6	6	6	6	6	-	-	-	-	-
			No. of Individ.	1	2	1	-	-	4	9	7	8	6	226	356	376	254	304	-	-	-	-	-
			No. of Clumps	-	-	-	-	-	23	29	28	15	17	12	12	8	10	16	14	15	18	26	26
3	16 mi. NE	1	No. of Species	2	2	1	1	1	5	5	5	5	5	6	7	7	7	6	-	-	-	-	-
			No. of Individ.	7	7	4	54	4	17	24	22	31	30	186	250	231	218	171	-	-	-	1	-
			No. of Clumps	-	-	-	-	-	7	11	7	12	19	8	40	21	25	36	29	74	48	53	55
		2	No. of Species	3	3	3	4	3	2	3	3	3	2	3	3	5	4	5	-	-	-	-	-
			No. of Individ.	4	3	3	6	3	1	2	2	2	1	223	258	168	218	232	-	-	-	1	-
			No. of Clumps	-	-	-	-	-	12	23	25	25	28	-	-	1	-	-	-	-	2	-	-

* Value estimated in 1973

Table 8 (cont'd):

Summary of the Ground Flora Populations in the Grids
Adjacent to the Wawa Vegetation Plots from 1969 to 1973

Plot No.	Location	Grid No.	Year	Trees					Shrubs					Herbaceous Plants					Grasses, Sedges, Mosses, Lichens				
				'69	'70	'71	'72	'73	'69	'70	'71	'72	'73	'69	'70	'71	'72	'73	'69	'70	'71	'72	'73
4	19 mi. NE	1	No. of Species	1	1	-	-	-	4	4	4	5	4	4	5	5	5	5	-	-	-	-	-
			No. of Individ.	1	1	-	-	-	24	31	26	32	29	384	692	436	556	550*	-	-	-	-	-
			No. of Clumps	-	-	-	-	-	76	54	51	31	38	-	-	-	-	-	1	8	10	10	13
		2	No. of Species	3	3	3	3	3	2	2	3	3	3	3	6	6	5	5	-	-	-	-	-
			No. of Individ.	38	37	18	61	20	3	2	2	2	3	54	328	253	235	245	-	-	-	-	-
			No. of Clumps	-	-	-	-	-	96	98	84	42	37	2	2	2	1	1	16	47	36	41	31
5	22 mi. NE	1	No. of Species	3	3	3	2	2	3	3	3	3	3	6	6	6	6	6	-	-	-	-	-
			No. of Individ.	15	15	8	6	8	7	5	5	6	5	62	103	108	86	100	39	24	18	36	27
			No. of Clumps	-	-	-	-	-	31	48	48	44	49	5	9	6	15	17	15	22	25	25	26
		2	No. of Species	2	2	2	2	2	4	4	4	3	2	5	5	5	4	5	-	-	-	-	-
			No. of Individ.	3	2	2	5	6	3	3	1	13	3	66	152	78	125	165	-	-	-	3	7
			No. of Clumps	-	-	-	-	-	8	11	23	20	22	22	14	41	22	17	11	10	19	17	17
6	24 mi. NE	1	No. of Species	1	-	-	-	-	3	4	3	3	2	4	5	5	5	5	-	-	-	-	-
			No. of Individ.	2	-	-	-	-	2	3	1	1	1	42	101	87	74	68	-	-	-	-	-
			No. of Clumps	-	-	-	-	-	Vaccinium Throughout					-	-	-	-	-	2	2	4	1	1
		2	No. of Species	-	-	-	-	-	4	4	4	4	3	3	4	5	4	4	-	-	-	-	-
			No. of Individ.	-	-	-	-	-	6	10	11	13	13	49	77	74	78	84	-	-	-	2	-
			No. of Clumps	-	-	-	-	-	13	16	16	20	16	-	-	-	-	-	7	4	5	4	8

* Value estimated in 1973

Table 8 (cont'd):

Summary of the Ground Flora Populations in the Grids
Adjacent to the Wawa Vegetation Plots from 1969 to 1973

Plot No.	Location	Grid No.	Year	Trees					Shrubs					Herbaceous Plants					Grasses, Sedges, Mosses, Lichens				
				'69	'70	'71	'72	'73	'69	'70	'71	'72	'73	'69	'70	'71	'72	'73	'69	'70	'71	'72	'73
7	38 mi. NE (Control)	1	No. of Species	2	2	2	2	2	2	2	2	2	2	7	7	6	5	6	-	-	-	-	-
			No. of Individ.	13	10	10	11	18	10	7	8	8	10	340	377	373	292	365	-	-	-	-	-
			No. of Clumps	-	-	-	-	-	2	2	2	2	2	1	-	-	-	-	3	7	7	18	13
		2	No. of Species	4	4	4	2	2	3	3	3	4	4	7	7	7	6	5	-	-	-	-	-
			No. of Individ.	29	17	14	3	3	6	7	7	28	42	193	236	236	92	84	-	-	-	-	-
			No. of Clumps	-	-	-	-	-	1	2	2	1	1	-	-	-	1	1	10	32	22	32	26
			No. of Species	2	2	3	3	2	1	2	2	2	1	3	3	3	3	3	-	-	-	-	-
			No. of Individ.	10	10	9	24	8	1	2	1	1	1	117	159	148	165	302	-	-	-	-	-
			No. of Clumps	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	40	43	37	25	34
8	35 mi. NW (Control)	1	No. of Species	2	2	3	3	2	1	2	2	2	1	3	3	3	3	3	-	-	-	-	-
			No. of Individ.	10	10	9	24	8	1	2	1	1	1	117	159	148	165	302	-	-	-	-	-
			No. of Clumps	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	40	43	37	25	34
		2	No. of Species	2	2	2	3	2	1	1	1	1	1	6	7	7	7	7	-	-	-	-	-
			No. of Individ.	10	8	5	15	5	-	-	-	-	-	147	148	123	107	131	16	12	13	4	7
			No. of Clumps	-	-	-	-	-	18	13	11	12	12	1	2	1	1	3	11	12	12	14	14

Table 9 : Concentrations of Various Chemical Elements in Vegetation collected at the Eight Study Plots in the Wawa area in 1970, 1971 and 1972 (Average of four (1970) and three (1971 and 1972) monthly collections)

Species: Trembling Aspen		Elements											
Plot No.	Location	ToS %			As ppm			Fe ppm			Zn ppm		
		1970	1971	1972	1970	1971	1972	1970	1971	1972	1970	1971	1972
1	16 km NE	<u>.31</u>	<u>.57</u>	<u>.61</u>	<u>22.8</u>	<u>9.1</u>	<u>8.1</u>	89	<u>124</u>	<u>256</u>	<u>380</u>	<u>377</u>	<u>391</u>
2	19 km NE	-	-	-	-	-	-	-	-	-	-	-	-
3	26 km NE	.22	.34	<u>.47</u>	<u>5.8</u>	2.2	2.5	56	71	62	<u>300</u>	250	267
4	30 km NE	-	-	-	-	-	-	-	-	-	-	-	-
5	35 km NE	.25	.35	.45	3.3	2.5	2.0	53	71	55	264	225	203
6	38 km NE	.22	.34	.37	<u>5.8</u>	2.3	1.8	60	90	68	<u>307</u>	235	178
*7	61 km NE	.21	.23	.31	1.9	1.5	1.1	57	72	63	190	168	179
*8	56 km NW	.21	.36	.30	0.7	0.9	0.8	51	87	65	151	178	158

Trembling Aspen not available at Plots 2 and 4

Species: White Birch		Elements											
Plot No.	Location	ToS %			As ppm			Fe ppm			Zn ppm		
		1970	1971	1972	1970	1971	1972	1970	1971	1972	1970	1971	1972
1	16 km NE	<u>.25</u>	<u>.49</u>	<u>.41</u>	<u>19.6</u>	<u>9.0</u>	<u>5.4</u>	51	<u>325</u>	<u>184</u>	226	<u>330</u>	<u>322</u>
2	19 km NE	<u>.24</u>	<u>.34</u>	<u>.43</u>	<u>14.1</u>	<u>6.2</u>	<u>5.7</u>	65	<u>155</u>	<u>129</u>	240	253	225
3	26 km NE	<u>.28</u>	<u>.28</u>	<u>.33</u>	<u>8.0</u>	3.1	3.5	38	115	92	252	270	256
4	30 km NE	<u>.24</u>	<u>.32</u>	<u>.33</u>	<u>9.9</u>	3.8	2.8	64	120	96	188	197	154
5	35 km NE	.18	<u>.31</u>	.26	<u>7.5</u>	3.0	1.3	55	96	78	198	290	255
6	38 km NE	.19	.26	.28	<u>6.6</u>	2.9	2.2	64	104	94	152	173	140
*7	61 km NE	.16	.17	.23	2.6	1.2	1.2	44	81	68	228	188	112
*8	56 km NW	.15	.19	.24	0.8	1.0	0.6	47	77	73	88	217	129

* Plots 7 and 8 are control plots

** Underlined values are markedly higher than control values

Table 9: Concentrations of Various Chemical Elements in Vegetation collected
(cont'd) at the Eight Study Plots in the Wawa area in 1970, 1971 and 1972
(Average of four (1970) and three (1971 and 1972) monthly collections)

Species: Mountain Maple		Elements											
Plot No.	Location	ToS %			As ppm			Fe ppm			Zn ppm		
		1970	1971	1972	1970	1971	1972	1970	1971	1972	1970	1971	1972
1	16 km NE	.24	<u>.35</u>	<u>.60</u>	<u>18.2</u>	5.9	5.3	85	<u>229</u>	<u>245</u>	37	44	74
2	19 km NE	<u>.39</u>	<u>.38</u>	<u>.52</u>	<u>7.8</u>	4.6	4.2	59	<u>128</u>	<u>147</u>	43	41	53
3	26 km NE	.17	.28	<u>.37</u>	<u>5.3</u>	3.3	3.0	52	<u>133</u>	108	40	35	32
4	30 km NE	-	-	-	-	-	-	-	-	-	-	-	-
5	35 km NE	.24	.29	<u>.45</u>	3.7	2.0	2.0	46	117	<u>128</u>	27	33	37
6	38 km NE	.16	.22	.27	3.7	1.6	1.9	46	86	91	37	36	54
*7	61 km NE	.19	.26	.27	1.9	1.1	1.0	58	81	76	45	33	52
*8	56 km NW	.20	.22	.19	0.6	0.7	0.9	69	93	71	33	34	41

Species: Showy Mountain Ash		Elements											
Plot No.	Location	ToS %			As ppm			Fe ppm			Zn ppm		
		1970	1971	1972	1970	1971	1972	1970	1971	1972	1970	1971	1972
1	16 km NE	<u>.21</u>	<u>.27</u>	<u>.51</u>	<u>15.0</u>	6.7	5.3	63	<u>250</u>	<u>164</u>	28	30	25
2	19 km NE	<u>.23</u>	<u>.37</u>	<u>.52</u>	<u>11.3</u>	4.6	2.7	39	<u>137</u>	<u>113</u>	25	21	23
3	26 km NE	<u>.20</u>	<u>.27</u>	<u>.40</u>	<u>6.6</u>	2.9	2.3	31	<u>117</u>	82	28	18	19
4	30 km NE	.18	<u>.29</u>	<u>.30</u>	<u>9.4</u>	2.5	1.6	31	96	91	24	23	16
5	35 km NE	.16	-	-	3.5	-	-	-	-	-	18	-	-
6	38 km NE	.14	.22	.21	4.5	2.5	1.7	40	124	79	24	17	22
*7	61 km NE	.13	.20	.16	1.4	1.4	1.0	37	88	86	27	25	39
*8	56 km NE	.14	.17	.16	0.6	0.7	0.9	43	90	67	31	24	60

* Plots 7 and 8 are control plots

** Underlined values are markedly higher than control values

Table 9: Concentrations of Various Chemical Elements in Vegetation and Soil
(cont'd) collected at the Eight Study Plots in the Wawa area in 1970, 1971
and 1972 (Average of four (1970) and three (1971 and 1972) monthly collections)

Species: Forage		Elements											
Plot No.	Location	1970	ToS % 1971	1972	1970	As ppm 1971	1972	1970	Fe ppm 1971	1972	1970	Zn ppm 1971	1972
1	16 km NE	.18	<u>.39</u>	<u>.44</u>	<u>8.4</u>	<u>4.4</u>	<u>5.4</u>	62	<u>120</u>	<u>101</u>	37	34	59
2	19 km NE	.16	<u>.43</u>	.28	<u>4.8</u>	3.3	<u>4.2</u>	49	<u>122</u>	63	40	36	73
3	26 km NE	.21	.16	.24	<u>5.6</u>	2.4	<u>4.0</u>	40	50	67	37	33	31
4	30 km NE	.15	.27	.25	<u>5.1</u>	3.9	2.0	48	69	54	50	26	43
5	35 km NE	.17	.24	.24	2.2	1.7	1.8	48	87	58	37	31	23
6	38 km NE	.16	.21	.20	3.0	2.3	1.5	46	71	49	39	47	77
*7	61 km NE	.16	.17	.22	0.9	1.1	1.2	72	74	49	35	30	53
*8	56 km NW	.21	.30	.20	0.5	1.0	1.1	53	63	49	50	41	51

Species: **Soil		Elements											
Plot No.	Location	1970	ToS % 1971	1972	1970	As ppm 1971	1972	1970	Fe % 1971	1972	1970	Zn ppm 1971	1972
1	16 km NE	<u>.05</u>	.03	.03	<u>56.7</u>	<u>56.5</u>	<u>48.4</u>	1.92	<u>2.83</u>	1.24	57	68	48
2	19 km NE	<u>.05</u>	<u>.06</u>	.03	<u>24.4</u>	<u>24.9</u>	<u>20.5</u>	1.92	<u>3.52</u>	2.06	23	63	82
3	26 km NE	.03	.02	.03	<u>9.6</u>	6.5	6.9	0.67	0.37	0.65	18	17	43
4	30 km NE	.03	.02	.02	<u>19.6</u>	<u>72.6</u>	<u>16.2</u>	2.20	1.83	1.65	36	37	64
5	35 km NE	.03	.02	.03	6.4	8.4	8.2	1.96	2.39	1.35	55	89	89
6	38 km NE	.02	.02	.03	4.1	6.9	11.0	1.36	1.27	1.49	21	24	70
*7	61 km NE	.02	.02	.02	2.1	4.9	3.2	0.85	0.75	0.67	24	27	79
*8	56 km NW	.01	.01	.02	0.7	2.0	4.1	0.08	0.10	0.32	3	9	54

* Plots 7 and 8 are control plots

** Average of two monthly collections

*** Underlined values are markedly higher than control values

Table 10: Summary of Analysis of Variance (F - Values) for
Different Chemicals in Vegetation in the Wawa
Area in 1970, 1971 and 1972

<u>Chemical</u>		<u>Sulphur</u>	<u>Arsenic</u>	<u>Iron</u>	<u>Zinc</u>
<u>Sources of Variance</u>	<u>Year</u>				
Species	1970	15.56**	12.03**	14.15**	110.35**
	1971	4.74**	5.16**	7.74**	77.09**
	1972	3.65**	0.38	2.76*	28.34**
Station	1970	9.35**	60.72**	6.27**	4.36**
	1971	8.68**	29.10**	10.96**	3.24**
	1972	13.78**	17.50**	12.03**	4.28**

** Significant at 1% level

* Significant at 5% level

Table 11 :

Sulphation Rates Recorded from 1970 to 1973 on the
Lead Peroxide Candles at the Vegetation Plots in
the Wawa Area Expressed as mgm SO₃/100 cm²/day

Plot No.	Location	June				*	July				August				Mean			
		1970	1971	1972	1973		1970	1971	1972	1973	1970	1971	1972	1973	1970	1971	1972	1973
1	10 mi. NE	1.31	1.29	1.82	1.92	-	2.47	1.41	1.70	.74	.67	1.42	1.05	1.03	1.47	1.55	1.56	
2	12 mi. NE	.89	.95	.94	.95	-	1.25	1.06	1.16	.34	.46	.61	.59	.61	.88	.87	.90	
3	16 mi. NE	.57	.42	.49	.52	.15	.46	.52	.48	-	.20	.26	.19	.59	.36	.42	.40	
4	19 mi. NE	.28	.42	.50	-	-	.55	.40	.99	.23	.20	.23	.28	.25	.39	.38	.63	
5	22 mi. NE	.35	.20	.48	.34	.12	.41	.34	.33	-	.19	.24	.20	.35	.26	.35	.29	
6	24 mi. NE	.25	.23	.20	.20	.09	.25	.24	.29	-	.13	.12	.11	.25	.20	.19	.20	
7 (Control)	38 mi. NE	.24	.12	.12	.03	.07	.16	.14	.21	.04	.08	.08	.08	.08	.12	.11	.08	
8 (Control)	35 mi. NW	.03	.11	.02	.05	.05	.01	.01	.03	.05	.01	.03	.01	.04	.04	.02	.03	

* Sinter plant shut down from July 4 to August 3, 1970

- Data invalid

Table 12:

The Correlation Coefficient and Regression Equation of
the Air Candle Sulphation Rate and the Total Sulphur (%)
in Vegetation Samples - Wawa 1970, 1971 and 1972

Plot No.	Distance and Direction from Sinter Plant	Average Sulphation Rate mgm SO ₃ /100 cm ² /day			Average Concentration of Total Sulphur (%) in Vegetation		
		<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>
1	10 mi. NE	1.03	1.48	1.55	0.24	0.44	0.51
2	12 mi. NE	0.61	0.88	0.87	0.25	0.36	0.44
3	16 mi. NE	0.57	0.36	0.42	0.22	0.27	0.36
4	19 mi. NE	0.25	0.39	0.38	0.19	0.30	0.28
5	22 mi. NE	0.35	0.26	0.35	0.22	0.30	0.34
6	24 mi. NE	0.25	0.20	0.19	0.17	0.25	0.26
7 (Control)	38 mi. NE	0.08	0.12	0.11	0.17	0.21	0.23
8 (Control)	35 mi. NW	0.04	0.04	0.02	0.18	0.26	0.21

	<u>1970</u>	<u>1971</u>	<u>1972</u>
Correlation Coefficient	$r = 0.84^*$	$r = 0.96^{**}$	$r = 0.95^{**}$
Regression Equation	$Y = 0.08x + 0.17$	$Y = 0.14x + 0.23$	$Y = 0.20x + 0.23$

** Significant at 1% level

* Significant at 5% level

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